IMPACTS OF DISCIPLINE MOBILITY ON SCIENTIFIC PRODUCTIVITY

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SUMMARY

Scientists acquire and deploy their technical skills and resources by "formal education," and the recent changes of research patterns to application-oriented research leads to an increase of multidisciplinary education in universities. The National Academy of Sciences suggests that undergraduate and graduate students should take multiple skills developed by experience in multiple disciplines (2005). This now raises the question, "is this multidisciplinary experience positively associated with their productivity throughout all disciplines?" This study examines curriculum vitae (CV) data from 447 scientists and engineers at academic research centers in the United States, ranging from post-doctoral researchers to full professors and research directors in order to figure out the pattern of scientific discipline trajectory and the relation of the scientists' discipline mobility to productivity.

This study shows that natural sciences have highest percentage of scientists who have the same bachelors degree field as their highest degree field and higher degree of mobility across the disciplines is negatively associated with their productivity. On the contrary, for life sciences, higher degree of mobility across the disciplines is positively associated with scientific productivity.

CHAPTER 1

INTRODUCTION

Scientific and technical (S&T) human capital includes not only the individual human capital endowments but also the sum total of researchers' tacit knowledge, craft knowledge, and know-how (Bozeman, Dietz and Gaughan, 2001). S&T human capital must recognize variation in educational background while human capital theory assumes that there is no variation in its predominant proxy variable, educational attainment, among scientists. This study focuses on the variation in educational background of scientists. The relation of the scientific life cycle to S&T human capital has been a topic considered by other researchers, but there are few studies for the pattern of scientific discipline trajectory and the relation of the scientists' discipline mobility to productivity. Many previous studies on scientific discipline networks have focused on co-authorship and co-citation. The co-authorship and co-citation concepts have many advantages for analyzing the relation of scientific disciplines to scientific productivity or collaboration pattern because of their verifiability, stability over time, data availability and ease of measurement (Katz and Martin, 1997). But they are no more than a partial indicator of scientists' collaboration and the relation among disciplines.

This study examines curriculum vitae (CV) data from 447 scientists and engineers at academic research centers in the United States, ranging from post-doctoral researchers to full professors and research directors in order to figure out the pattern of scientific discipline trajectory and the relation of the scientists' discipline mobility to productivity.

Within the context of policy, information on the pattern of scientific discipline trajectory may help formulate education policy in universities. Very little is known about the relation of the scientists' discipline mobility to productivity. So far, policy studies of S&T human capital have focused more on gender and collaboration than on scientists' education background (Bozeman and Corely, 2004). As long as many scientists have bachelor degrees in disciplines other than those of their highest degree, the effects of education background on their productivity need to be seriously examined in the study of research activity and performance as this study will provide a meaningful basis for both policy and theory.

CHAPTER 2

LITERATURE REVIEW

2.1 Scientific and Technical Human Capital

In general, human capital models (Becker, 1962; Schultz, 1963) have developed separately from social capital models (Bourdieu, 1986; Bourdieu and Wacquant, 1992; Coleman, 1988; Coleman, 1990), but in the practice of science and the career growth of scientists, the two are not easily disentangled.

S&T human capital is the sum total of scientific and technical and social knowledge, skills and resources embodied in a particular individual (Bozeman, Dietz and Gaughan, 2001). It is both human capital endowments, such as formal education and training, and social relations and network ties that bind scientists and the users of science together in “knowledge value collectives” (Rogers and Bozeman, 2001). S&T human capital is the unique set of resources the individual brings to his or her own work and to collaborative efforts. S&T human capital can be understood at the level of the individual and it is possible to measure the individual scientist’s training, skills and even tacit knowledge (Polanyi, 1967; 1969), as it is possible to measure individual ties to networks and transactions with those in networks.

In focusing on the individual, it is often most useful to think of S&T human capital in terms of the scientist’s professional life cycle. According to Levin and Stephan (1991), the gap in our knowledge of life cycles is in part owing to an inattention to the social dynamics of research processes and a failure to focus on the institutional contexts of these dynamics, that is, the factors central to a S&T human capital model. The S&T

human capital model is multi-level and is as important to the understanding of scientific fields, disciplines, and knowledge value collectives and alliances (Rogers and Bozeman, 2001) as it is to an understanding of individual scientists' career trajectories. Scientific networks are crucial to scientists throughout the professional life cycle because these networks consistently affect scientific work and even the ability to obtain work. The networks include not only scientists themselves, but a variety of other actors who use and enable science, including funding agents, vendors, entrepreneurs, equipment developers, technicians, public officials, among others.

S&T human capital includes knowledge and skills that are cognitive-rational as well as knowledge and skills that are political-social. Thus, S&T human capital includes not only knowledge of phenomena or skills to set up scientific apparatus, but also knowledge of how to manage a team of junior researchers, post-docs and graduate students. S&T human capital includes knowledge about government agencies' funding priorities and about the ways ideas are reviewed and perceived. It includes knowledge about the expertise of other scientists. It is the sum of skills, knowledge, and social relations needed to participate in science.

2.2 Disciplines and Permeation of Boundaries

The term *discipline* connotes the tools, methods, procedures, exempla, concepts, and theories that account coherently for a set of objects or subjects (OECD, 1972). Over time they are shaped and reshaped by external contingencies and internal intellectual demands. In this manner a discipline comes to organize and concentrate experience (Goodlad, 1979) into a particular "world view (Miller, 1982)."

A discipline has different degrees of formality and organization. R. D. Whitley (1978) has distinguished restricted sciences that are highly specific in subject and mathematical precision from configurational sciences, such as social and life sciences. Richard Rose (1976) distinguished consensual from nonconsensual fields, and Thompson et al. (1969) contrasted highly codified fields (mathematics and the natural sciences) to less codified fields (humanities and to a lesser extent the social sciences). Likewise, Thompson and Brewster (1978) distinguished high-paradigm fields such as physics and chemistry from low-paradigm fields such as sociology and political science. Stephen Toulmin (1972) distinguished compact disciplines (the better-established physical and biological sciences) from both would-be disciplines (the behavioral sciences) and nondisciplinary activities (ethics and philosophy). Achie Baum (1977) also distinguished narrow specialism, which concentrates on the division of functions, from broad specialism, which is open to their interdependence.

Disciplines also have different degrees of receptivity, and they have different growth patterns. Some develop without "definitional closure," and almost all disciplines have periods of definitional competition (Rich and Warren, 1980). Disciplines with well-established vocational fields will tend to be eclectic rather than purist in their epistemological conception of themselves (Heckhausen, 1972). Other disciplines have also been open from their origin. These beliefs are reinforced by value-laden terminology that authors of handbooks, textbooks, and knowledge histories use. They describe some disciplines, especially the sciences, as hard, tight, restrictive, neat, narrow, compact, homogeneous, and mature. They distinguish other disciplines, especially the humanities and some of the social sciences, by the rhetorical foils of softness and breadth.

The latter are said to have high degrees of differentiation and to be in a state of preparadigmatic development (Becher, 1989).

Impermeable boundaries among disciplines are associated with tightly knit, convergent communities. These communities presumably have clear boundaries, circumscribed domains, and “neat” problems that are controlled through cognitive restriction and social consensus. Pantin’s (1968) notion of “restricted” disciplines stipulates that most physical sciences, especially physics and chemistry, will exhibit strong linkage between research areas but lesser ties with other disciplines. In contrast, the humanities and social sciences are associated with greater permeability. They are considered more holistic, personal, value laden, and less codified. Loosely knit, divergent groups are thought to have a more fragmented, less stable, less theoretically specific, and more open-ended epistemological structure. Their boundaries are likely to be more open, their cognitive border zones more ragged and ill defined. Pantin’s notion of “unrestricted” disciplines stipulates that most social sciences, with the exception of economics, will exhibit diffuse links among research areas both within and outside the discipline (Klein, 1996).

Two kinds of disciplines, the applied and the synoptic, are associated with such high permeability that they are often described as “inherently interdisciplinary.” Disciplines emphasizing application and having well-established vocational fields tend to be more eclectic than purist in their epistemological conception of themselves (Heckhausen, 1972). Many degree programs in medicine, engineering, architecture, management, public administration, social work, education, and law involve courses, or course elements, focused on integration or complex issues.

Rinia et al. (2002) analyzed knowledge exchange between disciplines at a global level, by analyzing cross-disciplinary citations in journal articles, based on the world publication output in 1999. In the study, it is shown that high levels of self-citation in most cases correlate with the basic or applied character of a field. In physics, the highest self citing rate is found. Publications in mathematics, chemistry and life sciences disciplines show a high share of self-citations. In more applied and technical fields such as engineering and agriculture these shares are considerably lower.

2.3 Scientific Productivity and Collaboration

For academic scientists, research productivity is frequently measured by the number of publications or patents. As a measure of the output of research, research productivity has a direct and indirect relationship with a variety of factors such as collaboration, grants (Arora and Gambardella, 1996; Gaughan and Bozeman, 2002; Godin, 2003), organization (Long, 1978; Long and McGinnis, 1981), family (Kyvik, 1996; Bellas and Toutkoushian, 1999), age (Meltzer, 1949; Zuckerman, 1972; Lawrence and Blackburn, 1988; Stephan and Levin, 1992), quality of graduate training (Crane, 1965), quality of department (Cole & Cole, 1967; Allison and Long, 1990), gender (Reskin, 1977; Xie and Shauman, 1998; Mahlck, 2001), motivation (Tien and Blackburn, 1996), and time for research (Fox, 1992).

Especially, many scientists have paid attention to the relationship between scientific productivity and collaboration since De solla Price and Beaver (1966) found that “there is a good correlation between the productivities and the amount of collaboration of authors.” Crane (1972) explained the dynamics of collaboration in terms of “invisible colleges” and argued that these institutional dynamics were responsible for the exponential growth of scientific publication. Zuckerman’s study (1967) of 41 Nobel laureates showed a strong relationship between collaboration and productivity. In general, laureates published more and were more apt to collaborate than a matched sample of scientists. Miranda Lee Pao (1982) identified a strong relationship between collaboration and productivity in musicology. Though only 15% of the literature of musicology was the result of collaborative authorship, the most collaborative musicologists were also the most productive. Applying a normalized diversity measure to study the productivity of authors, Pao (1982) found a high degree of correlation between productivity and collaboration in computational musicology. Pravdic and Oliuic-Vukovic (1986) analyzed collaborative patterns in chemistry at both the individual and the group level. They found that scientific output as measured by publications is closely dependent on the frequency of collaboration among authors.

In early research about motives for collaboration, Beaver and Rosen (1979) identified 18 motives – access to special equipment of facilities, access to special skills, access to unique materials, access to visibility, access recognition, efficiency in use of time, efficiency of use of labor, to gain experience, to train researchers, to sponsor a protégé, to increase productivity, to multiply proficiencies, to avoid competition, to surmount intellectual isolation, need for additional confirmation of evaluation of a problem, need for stimulation of cross-fertilization, spatial propinquity, and accident or serendipity. They found that about half of the motives were related to the desire of enhancing productivity. Katz and Martin (1997) articulated several reasons why the level of research collaboration has been growing over the last 30 years: the escalating instrumentation costs of conducting fundamental science at the research frontier, the substantial fall in the cost of travel and communication, the growing importance of networks and interaction, the complexity of instrumentation, the interdisciplinary nature of research, and the political factors encouraging collaboration.

2.4 Incentives for discipline mobility

From human capital theory, financial returns play an important role in students' choice of university degrees and students understand how such differ across degrees (Grey Becker, 1964). Mangematin (2000) examined incentives for students to invest in a PhD by means of a survey on 400 engineering science PhD students. The study claims that the choice of seeking a PhD is driven by three main considerations as follows;

1) The PhD is needed to become an academic. It is seen as a degree dedicated to academia.

2) As the doctorate is the highest grade, completing a PhD is seen as an investment in human capital. The positive relationship between human capital, rate of employment and wages is supposed to apply at the doctoral level as well. Thus, investing in the highest university grade is a rational attitude for students (Freeman, 1986, 1989).

3) When employment prospects are low for graduate students, the period of research assistance or teaching assistance during which the PhD is completed can be considered as a first job experience.

Discontent with the state of one's discipline could be one answer to the main question "Why do certain students or scientists of a specific field move to other disciplines?" Hagstrom (1964) claimed that scholarly anomie was the main reasons of disciplinary discontent. Defining anomie as "the loss of solidarity following a general breakdown in the exchange of information and recognition”, he argued that mathematicians often do not see different lines of mathematical research as being closely related, and that mathematicians in a given research specialty often do not view accomplishments in other specialties as important to their own work. According to Hagstrom, this condition makes it difficult for mathematicians to obtain recognition for their research accomplishments, and they consequently often lose confidence in the importance of their research.

Collins (1986) correspondingly analyzed perceptions that the field of sociology is in the doldrums. Noting that the number of sociologists grew rapidly between the early 1960s and mid-1970s and that research specialization proceeded swiftly, Collins argued that these changes in the size and structure of their discipline made it more difficult for individual sociologists to achieve discipline-wide recognition for their research. According to Collins, during the 1980s these conditions led many sociologists to judge most sociological research as trivial and uninteresting and to believe that sociology was making little progress.

Another possible reason for pessimism about the intellectual state of one’s field is low consensus – widespread disagreement on the relative importance of various research topics and on the theories and methods appropriate for studying a given topic. Hagstrom (1964) argued that, like anomie, lack of consensus often leads scholars to lose confidence in the value of their research because they receive little recognition for it.

Hargens and Kelly-Wilson (1994) examined the extent to which variation in pessimism about the intellectual state of one’s field could be explained by theories that attribute it to field-level variation in anomie and consensus. They claimed that both anomie and consensus exert strong effects on the average levels of scholarly pessimism within fields. In addition, there is an interaction effect involving the level of consensus in a field and whether the field is primarily pure or applied.

CHAPTER 3

HYPOTHESES

3.1 “Impermeability” in the discipline mobility of scientists

As Klein claimed (1996), many studies have divided disciplines into two types, “restricted” and “unrestricted,” and these two kinds of disciplines are related to the degree of permeability. According to Pantin (1968), most natural sciences, especially physics and chemistry, have strong linkages between research areas but weaker ties with other disciplines. On the other hand, the humanities and social sciences are associated with greater permeability. Rinia et al. (2002) found that natural sciences including mathematics, physics and chemistry have high levels of self-citation and the humanities and social sciences has low levels of self-citation (Table 1). In other words, natural sciences are more restricted disciplines and their boundaries are likely to be less open than humanities and social sciences.

Similarly, scientists’ discipline mobility might be influenced by discipline characteristics and their mobility might have limitations associated with their primary discipline.

> H1: Because of relatively high degree of restrictions and specifications, natural sciences will be most likely to display lowest degree of mobility across the disciplines.

H2: Because of relatively low degree of restrictions and specifications, social sciences will be most likely to display highest degree of mobility across the disciplines.

Table 1. Shares of references per discipline in the world total of publications 1999. Numbers and shares are based on weighted numbers of references

Cited discipline (j)	Percentage references to: Basi	Biol	Chem	Clin	Comp	Engi	Envi	Food	Geo	Mate	Math	Mult	Phar	Phys	Psyc	Total	Weighted number of ref's
Citing discipline (i)																	
Basic Life Sciences	**62.9**	2.6	1.6	15.0	0.1	0.1	0.3	1.9	0.1	0.1	0.0	11.5	2.3	0.5	1.0	100	110844
Biology	31.4	**35.8**	1.0	5.1	0.1	0.2	8.3	5.4	1.4	0.1	0.4	7.9	1.0	0.5	1.3	100	21534
Chemistry	7.4	0.5	**63.2**	2.7	0.2	1.3	0.9	1.7	0.7	4.9	0.1	2.8	1.3	12.3	0.0	100	71082
Clinical Life Sciences	22.2	0.6	0.6	**66.9**	0.1	0.4	0.1	1.2	0.0	0.1	0.1	4.9	2.1	0.3	0.5	100	149403
Computer Sciences	5.8	0.8	2.4	3.0	**45.3**	19.2	0.5	0.3	1.1	0.5	10.0	2.5	0.2	7.9	0.6	100	15102
Engineering & Technology	2.8	0.5	5.1	6.7	5.2	**39.1**	3.4	1.2	3.7	6.2	2.6	1.4	0.3	21.5	0.1	100	31808
Environmental Sciences	7.1	12.9	4.0	2.8	0.1	3.8	**44.5**	6.9	9.6	0.3	0.3	4.1	2.4	0.7	0.5	100	15058
Food, Agricult. & Biotechn.	26.0	7.1	3.8	14.7	0.1	0.6	4.1	**35.0**	1.4	0.5	0.1	4.4	1.5	0.3	0.4	100	28291
Geo Sciences	1.0	1.8	1.8	0.2	0.3	2.8	6.6	1.5	**69.8**	0.5	0.2	7.2	0.1	6.1	0.0	100	19417
Materials Sciences	1.3	0.1	14.8	1.4	0.2	5.2	0.2	0.7	0.7	**49.4**	0.1	2.3	0.2	23.6	0.0	100	34528
Mathematics	1.3	1.7	0.5	1.5	4.9	5.6	0.4	0.2	0.5	0.3	**72.9**	1.2	0.1	8.8	0.1	100	19479
Multidisciplinary Sciences	45.5	4.0	2.2	10.0	0.2	1.0	1.3	1.7	3.9	0.8	0.6	**20.1**	1.4	6.7	0.6	100	9622
Pharmacology	31.7	1.2	3.3	29.0	0.1	0.3	1.6	1.6	0.1	0.2	0.1	5.4	**23.2**	0.2	2.1	100	16218
Physics	1.5	0.1	6.4	0.7	0.4	3.5	0.1	0.1	1.5	3.5	0.5	2.8	0.1	**78.8**	0.0	100	95435
Psychology & Psychiatry	33.8	4.7	0.1	16.4	0.2	0.2	1.4	1.0	0.0	0.0	0.1	5.1	8.1	0.3	**28.5**	100	6095
Total	21.6	2.8	9.9	21.0	1.6	3.8	2.2	2.9	3.1	4.1	2.7	5.4	1.9	16.3	0.7	100	643916

SOURCE: Rinia, Ed J., Thed N. Van Leeuwen, Eppo E. W. Bruins, Hendrik G. Van Vuren and Anthony F. J. Van Raan (2002) Measuring knowledge transfer between fields of science. *Scientometrics*. 54(3):352

3.2 The relation of the scientists' discipline mobility to productivity

Hackhausen (1972) described the applied disciplines as "inherently interdisciplinary." Disciplines focusing on application tend to be more eclectic than purist in their epistemological conception of themselves. These disciplines involve course, or course elements, focused on integration or complex issues. Therefore, in disciplines emphasizing application, higher degree of mobility across the disciplines might be positively associated with their productivities.

H3: In disciplines such as applied sciences, life sciences, and social sciences emphasizing application, higher degree of mobility across the disciplines might be positively associated with their productivities.

H4: In natural sciences, restricted and highly codified, lower degree of mobility across the disciplines might be positively associated with their productivities.

CHAPTER 4

DATA AND METHODS

4.1 Data and Limitations

The data for this study are based on Research Value Mapping Program (RVM)[1]. Curriculum Vitae (CV). Their target population was scientific researchers working in multidisciplinary work groups or research areas, especially in centers funded by the National Science Foundation and by the Department of Energy. CVs were collected by e-mail in 2000 and the CV data had 3000 variables of demographic data, degree data, job data, publication data, patent data, professional affiliation data, and grant award data. CVs that had partial data were deleted. The final number of CVs coded and analyzed for this study was 447. The CV database include 63% tenured faculty, 37% non-tenured faculty or post-doctoral researchers, 86% males, 14% females, 70% native born and 30% immigrant scientists. The gender ratio and native/immigrant ratio in this sample is close to the national level.

Although an ideal data would be drawn from the total population of the scientists in U.S. without any sampling and coverage error, the sample used for this study is drawn from those who are affiliated with university research centers. For this reason, scientists of the sample may have more grant opportunities than the general population of academic scientists because the centers are supported heavily by the government and industrial research and development. Therefore, scientists in the sample may be more

[1] RVM stands for Research Value Mapping Program, a research project supported by NSF and DOE. It is located in the School of Public Policy at the Georgia Institute of Technology, Atlanta, GA.

productive than nonaffiliated scientists, and the sample may be biased toward higher productivity compared with the general population of academic scientists.

4.2 Classification of Disciplines

In this study, a three-level hierarchical classification scheme has been constructed. I referred the procedure employed by Katz and Hicks (1995) and created two higher levels, a level 2 and 3, in the classification hierarchy and discipline. A level 2 comprises 15 categories and a level 3 comprises 5 categories. Some scientists do not coincide precisely with fields and subfields of science and care must be taken about boundaries and overlaps. All scientists are assigned to one unique field in the following classification scheme.

- Natural Sciences (N)
    - Mathematical Sciences (NM)
    - Physical Sciences (NP)
    - Chemical Sciences (NC)
    - Earth Sciences (NE)
- Applied Sciences (A)
    - Information, Computer and Communication Technology (AI)
    - Engineering (AE)
- Life Sciences (L)
    - Biological Sciences (LB)
    - Agricultural Sciences (LA)
    - Medical and Health Sciences (LM)

Social Sciences (S)

Social and behavioral sciences (SS)

Economics and business (SE)

Humanities (H)

Languages and literature (HL)

History (HH)

Fine and Applied arts (HF)

Philosophy, Religion, and Theology (HP)

A level 1 has 74 categories that are equivalent to departments of university (OECD, 2002). Table 2 provides the classification of disciplines and number of respondents.

Table 2. Discipline classification and number of respondents

Level 3	Level 2	Level 1	N
Natural Sciences (N)	**Mathematical Sciences (NM)**	Mathematics (NMM)	5
		Statistics (NMS)	1
		Others (NMO)	0
	Physical Sciences (NP)	Physics (NPP)	44
		Astronomy (NPA)	2
		Others (NPO)	9
	Chemical Sciences (NC)	Chemistry (NCC)	46
		Others (NCO)	0
	Earth Sciences (NE)	Earth science (NEE)	0
		Geology (NEG)	4
		Meteorology (NEM)	3
		Oceanography (NEC)	1
		Others (NEO)	0

Table 2. (Continued)

Level 3	Level 2	Level 1	N
Applied Sciences (A)	**Information, Computer and Communication Technology (AI)**	Computer Science (AIC)	23
		Computer systems analysis (AIS)	1
		Computer programming (AIP)	0
		Data processing technology (AID)	0
		Information services and systems (AII)	0
		Others (AIO)	1
	Engineering (AE)	Aerospace, aeronautical, astronautical engineering (AEA)	4
		Agricultural engineering (AEG)	1
		Architectural engineering (AER)	2
		Bioengineering and biomedical engineering (AEB)	3
		Chemical engineering (AEC)	45
		Civil engineering (AEV)	19
		Computer/systems engineering (AES)	2
		Electrical engineering (AEE)	51
		Engineering sciences (AEN)	3
		Environmental engineering (AEM)	5
		General engineering (AEJ)	2
		Industrial engineering (AEI)	6
		Materials engineering (AET)	19
		Mechanical engineering (AEH)	28
		Mining and minerals engineering (AEK)	1
		Naval architecture and marine engineering (AEL)	0
		Nuclear engineering (AEU)	0
		Petroleum engineering (AEP)	0
		Other engineering (AEO)	1
Life Sciences (L)	**Biologocal Sciences (LB)**	Biology (LBB)	13
		Botany (LBT)	2
		Cell and molecular biology (LBC)	2
		Ecology (LBE)	1
		Genetics (LBG)	2
		Microbiology, Bacteriology, Virology (LBM)	5
		Biochemistry and biophysics (LBP)	20
		Zoology (LBZ)	6
		Other biological sciences (LBO)	15
	Agricultural Sciences (LA)	Animal sciences (LAA)	0
		Food sciences (LAF)	1
		Plant sciences (LAP)	0
		Other agricultural (LAO)	1
	Medical and Health Sciences (LM)	Medicine (LMM)	12
		Health sciences (LMH)	1
		Pharmacy (LMP)	2
		Physiology (LMS)	3
		Others (LMO)	3

Table 2. (Continued)

Level 3	Level 2	Level 1	N
Social Sciences (S)	**Social and behavioural sciences (SS)**	Psychology (SSP) Sociology (SSS) Political science (SSP) Anthropology (SSA) Geography (SSG) Public affairs (SSB) Education (SSE) Communication (SSC) Others (SSO)	10 1 2 0 0 2 1 1 2
	Economics and business (SE)	Economics (SEE) Business (SEB) Accountancy (SEA) Other business management (SEM) Others (SEO)	1 3 0 3 0
Humanities (H)	**Languages and literature (HL)**	Languages and literature (HLL)	0
	History (HH)	History (HHH)	0
	Fine and Applied arts (HF)	Fine and Applied arts (HFF)	0
	Philosophy, Religion, and Theology (HP)	Philosophy, Religion, and Theology (HPP)	0
Total			447

4.3 Discipline Mobility

The scientists' discipline mobility is a measure of how a scientist's discipline of highest degree is different from his or her bachelor discipline. The way to measure mobility is to use 4 dummy variables: no change, change in level 1, level 2, and level 3. For instance, if a scientist majored in physics at the undergraduate level but received a PhD in biology, the change of discipline was in level 3 and the dummy variable of level 3 is 1 and others are 0.

4.4 Scientific Productivity and Number of Collaborators

A simple number of publications is most frequently used as an indicator for scientific productivity. The simple count is the number of refereed scientific articles. It allows equal treatment for each author, which results in giving a full credit to each of the authors regardless of who happens to be the first or the last author. In this study, the data do not allow having a weighted measure of publication because the sample came from several disciplines, not from one specific discipline. Nor do the data permit quality comparisons among the journals or impact ratings. After all journal articles were counted, the total number of publications was divided by the number of years since the author's doctoral degree.

Research collaboration is defined as "working closely with others to produce new scientific knowledge or technology." This study uses the number of collaborators scientists have had over the past twelve months.

4.5 Methods

This study uses a linear regression analysis in order to examine the relationship between the discipline mobility and scientific productivity. In this analysis, common independent variables are gender, number of collaborators, and 4 dummy variables: no change, a discipline change in level 1, level 2, and level 3.

CHAPTER 5

FINDINGS

5.1 The pattern of discipline mobility of scientists

I examine scientists' bachelors and highest degrees by disciplines. I hypothesized that natural sciences are most likely to display the lowest degree of mobility across disciplines and social sciences have the highest degree of mobility across disciplines. Figure 1 shows the percentage distributions of three kinds of mobility by fields of sciences. This figure shows that more than half (59.2%) of total scientists have different bachelor degrees from their highest degrees. Natural sciences have the lowest degree of mobility (19%) across disciplines and life sciences have the highest degree of mobility (77%) across disciplines. It means that 19 % of scientists in natural sciences and 77 % of scientists in life sciences have different bachelor degrees from their highest degrees. The result might imply that scientists in life science have relatively more different discipline backgrounds. Interestingly the mobility in level 2 is the lowest percentage throughout all fields. This indicates that scientists who move into other fields over level 1 tend to move to quite different fields from their bachelors discipline.

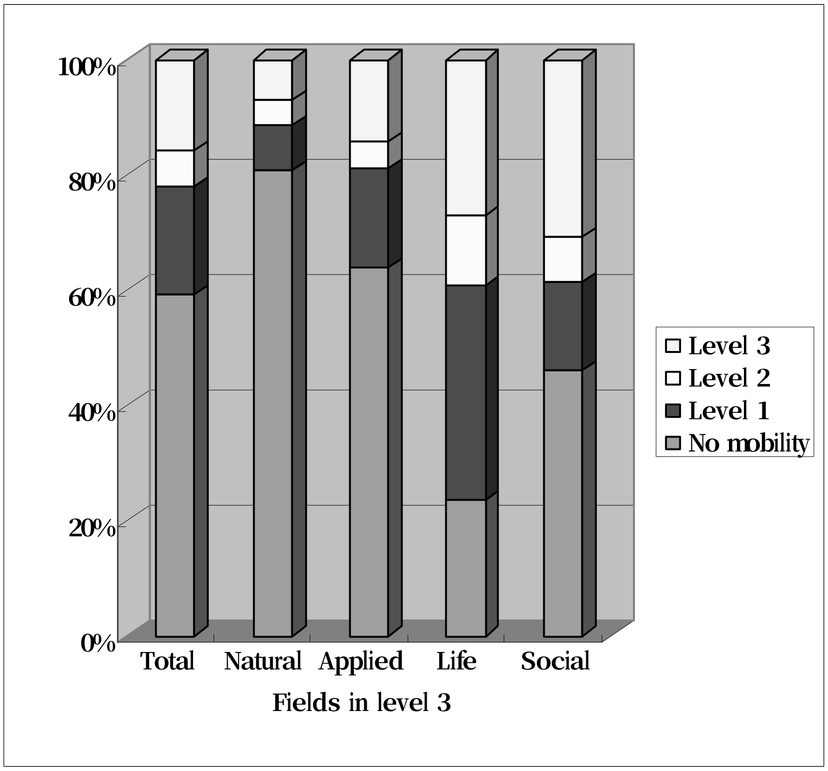

Figure 1. Percentage distributions of three kinds of mobility by field of science

Table 3 shows a field to field distribution of scientists' bachelors and highest degrees in level 2 and 3. For instance, there are 6 scientists in mathematical science (NM), and the bachelors disciplines of 5 scientists are mathematical science and the bachelors discipline of 1 scientist is engineering (AE). The number of scientists is transformed into grey scale in Table 4 in order to understand the whole pattern of discipline mobility. In natural sciences that Pantin (1968) described as "restricted" disciplines, 94% of scientists come from natural sciences and only 6% of scientists have applied sciences as their bachelors degree field. This result is in line with expectations and previous studies that analyzed the citation of scientific publications (Rinia et al., 2002; Bourke and Butler, 1998). The area to be surrounded with dash-boundary indicates that none of natural scientists have life, social, or humanities field as their bachelor degree field there.

Table 3. Bachelor and highest degree of scientists

Bachelor Degree \ Highest Degree		Natural				Applied		Life			Social		N
		NM	**NP**	**NC**	**NE**	**AI**	**AE**	**LB**	**LA**	**LM**	**SS**	**SE**	
Natural	**NM**	5	1			1	3	1		1	1		13
	NP		51	1	2		9	2			1		66
	NC			42			7	6					55
	NE		1		5		2						8
Applied	**AI**					12	1	8					21
	AE	1	2	3	1	10	165					2	184
Life	**LB**						3	46		10	2		61
	LA							1	1				2
	LM									7			7
Social	**SS**							1		1	13		15
	SE						1		1	1	2	3	8
Human	**HL**						1	1				1	3
	HF									1			1
	HP					2						1	3
Total		**6**	**55**	**46**	**8**	**25**	**192**	**66**	**2**	**21**	**19**	**7**	**447**

Table 4. Bachelor and highest degree of scientists by gray scale

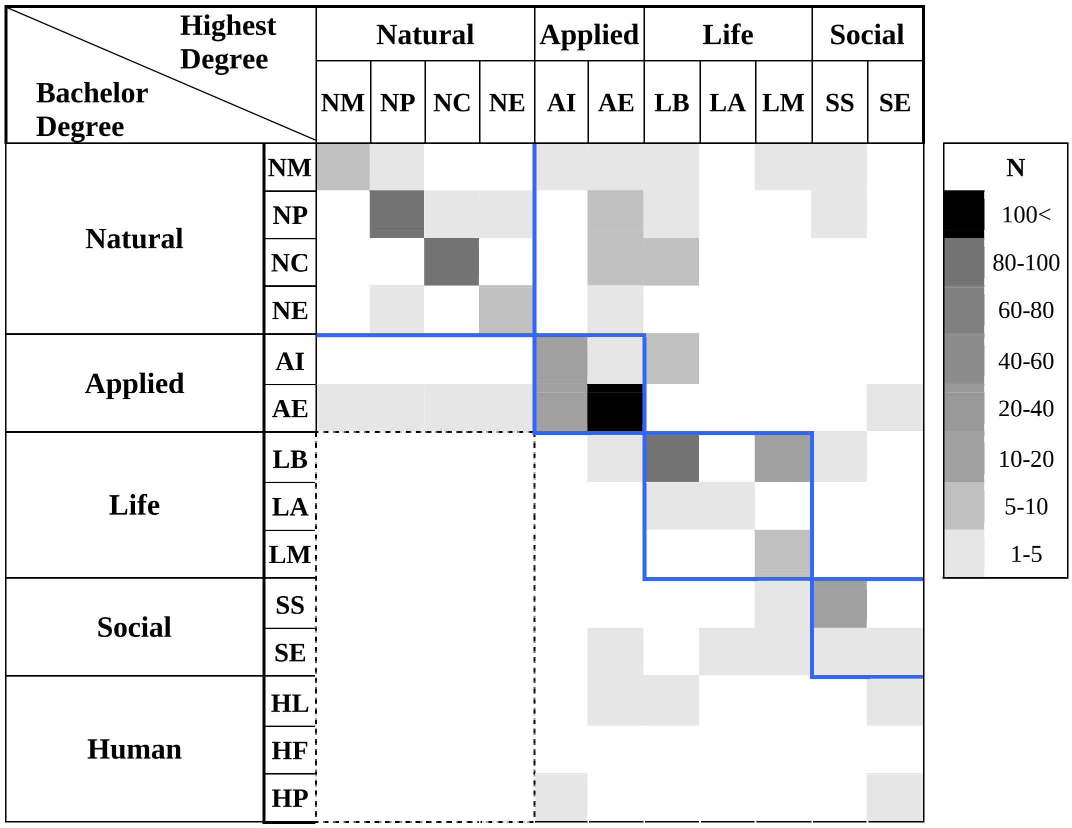

Table 5 calculates percentages of scientists who have the same bachelors degree field as their highest degree field. The highest percentage (94%) is in natural sciences and social sciences have the lowest percentage (69%). This difference corresponds with the discipline distinctions in previous research – restricted and configurational sciences (Whitley, 1978), consensual and nonconsensual sciences (Rose, 1976), highly codified and less codified sciences (Thompson et al., 1969), high-paradigm and low-paradigm sciences (Thompson and Brewster, 1978).

Table 5. Percentage of scientists to have the same bachelors degree field as their highest degree field

Natural Sciences	**94%**
Mathematical Sciences	83%
Physical Sciences	93%
Chemical Sciences	91%
Earth Sciences	63%
Applied Sciences	**87%**
Information, Computer and Communication Technology	48%
Engineering	86%
Life Sciences	**73%**
Biological Sciences	70%
Agricultural Sciences	50%
Medical and Health Sciences	33%
Social Sciences	**69%**
Social and behavioral sciences	68%
Economics and business	43%

5.2 The relation of the scientists' discipline mobility to productivity

I hypothesized that scientific productivity has a significant relationship with scientists' discipline mobility. I examine the correlations for selected variables including mobility variables and productivity, and I regress the annual average publication of career total (normal count to all publications) since doctoral degree obtained on gender, the number of collaborators, and 4 dummy variables: no change, a discipline change in level 1, level 2, and level 3. In this regression, I show the mobility dummies only when they are significant.

Correlations for selected variables and productivity

Table 6 gives correlations between selected variables and discipline mobility. As previous studies claimed, there is a significant positive relationship between total number of collaborators and average collaboration and annual average publication of career total (.195 $p=<.000$). Table 6 shows that there is a significant positive relationship between natural sciences (dummy variable for degree field) and no mobility. The relationship between applied sciences and mobility variables is insignificant. On the other hand, life sciences have a significant relationship with all mobility variables.

Table 6. Correlations for selected variables and productivity

		1	2	3	4	5	6	7	8	9	10	11
1. Average publication	Pearson Correlation	1										
	Sig. (2-tailed)	.										
2. Gender	Pearson Correlation	.114	1									
	Sig. (2-tailed)	.016	.									
3. Total number of collaborators	Pearson Correlation	.195	.071	1								
	Sig. (2-tailed)	.000	.177	.								
4. No mobility	Pearson Correlation	.046	.073	.081	1							
	Sig. (2-tailed)	.329	.123	.123	.							
5. Mobility in level 1	Pearson Correlation	-.098	-.036	-.064	-.578	1						
	Sig. (2-tailed)	.037	.450	.222	.000	.						
6. Mobility in level 2	Pearson Correlation	.003	.045	.012	-.311	-.124	1					
	Sig. (2-tailed)	.956	.344	.818	.000	.009	.					
7. Mobility in level 3	Pearson Correlation	.041	-.090	-.048	-.522	-.208	-.112	1				
	Sig. (2-tailed)	.385	.057	.364	.000	.000	.018	.				
8. Natural sciences	Pearson Correlation	.149	.075	.007	.260	-.164	-.046	-.143	1			
	Sig. (2-tailed)	.002	.114	.889	.000	.000	.329	.002	.			
9. Applied sciences	Pearson Correlation	-.113	.084	.166	.091	-.033	-.067	-.043	-.572	1		
	Sig. (2-tailed)	.017	.077	.001	.053	.487	.158	.359	.000	.		
10. Life sciences	Pearson Correlation	.012	-.077	-.186	-.360	.234	.126	.152	-.293	-.485	1	
	Sig. (2-tailed)	.400	.105	.000	.000	.000	.008	.001	.000	.000	.	
11. Social sciences	Pearson Correlation	-.059	-.188	-.057	-.066	-.021	.015	.101	-.146	-.242	-.124	1
	Sig. (2-tailed)	.216	.000	.280	.165	.651	.755	.032	.002	.009	.009	.

Natural science

Table 7 provides the OLS regression results for natural sciences. For this regression model, the mobility in level 3 is significant and the regression coefficient is negative (β=-.24, p<.01). Therefore, researchers who have mobility in level 3 are likely to have a lower productivity. The result implies that higher degree of mobility across the disciplines is negatively associated with their productivities in natural sciences, restricted, highly codified, or high-paradigm disciplines. The ANOVA results of this regression indicate that the model is statistically significant with an F-value of 2.680 (P<.001). Neither gender nor the number of collaborators is significant in this model.

Table 7. OLS regression analysis – Natural science

	Unstandardized Coefficients	Std. Error	Standardized Coefficients	t	Sig.
	B		Beta		
(Constant)	4.982	1.079		4.617	.000
Gender	.211	1.118	.017	.189	.851
Mobility in level 3	-3.234	1.235	-.240	-2.618	.010

a. ANOVA : F=2.680 (P<0.001)
b.Dependent Variable: annual average publication of career total (normal count--all publications) since doctoral degree obtained

Applied science

Table 8 gives the OLS regression results for applied sciences. For this regression model, none of the mobility variables are significant. The only other variable that is significant is the number of collaborators (β=0.15, p<.04). It implies that the scientific productivity is positively associated with the number of collaborators or other factors regardless of scientists' discipline mobility in applied sciences. The ANOVA results of this regression indicate that the model is statistically significant with an F-value of 3.558 (P<.001).

Table 8. OLS regression analysis – Applied science

	Unstandardized Coefficients	Std. Error	Standardized Coefficients	t	Sig.
	B		Beta		
(Constant)	1.574	.686		2.294	.023
Gender	1.257	.650	.141	1.933	.055
Total number of collaborators	4.144E-02	.020	.150	2.056	.041

a. ANOVA : F=3.558 (P<0.001)
b. Dependent Variable: annual average publication of career total (normal count--all publications) since doctoral degree obtained

Life science

Table 9 shows the OLS regression results for life sciences. For this regression model, the mobility in level 3 (β=0.38, p<.003)and the number of collaborators (β=0.28, p<.022) are significant and the regression coefficients are positive. In life sciences, as opposed to natural sciences, higher degree of mobility across the disciplines (level 3) is positively associated with scientific productivity. The ANOVA results of this regression indicate that the model is statistically significant with an F-value of 6.210 (P<.001). Gender is insignificant in this model.

Table 9. OLS regression analysis – Life science

	Unstandardized Coefficients	Std. Error	Standardized Coefficients	t	Sig.
	B		Beta		
(Constant)	-11.464	4.698		-2.440	.019
Gender	2.720	1.559	.200	1.745	.088
Mobility in level 3	4.805	1.549	.382	3.103	.003
Total number of collaborators	.205	.087	.284	2.367	.022

a. ANOVA : F=6.210 (P<0.001)
b. Dependent Variable: annual average publication of career total (normal count--all publications) since doctoral degree obtained

Social science

Table 10 provides the OLS regression results for social sciences. "No mobility" variable is significant and the coefficient has a positive sign (ß=.465, p<.017). Therefore, scientists who the same bachelors degree field as their highest degree field are likely to have higher productivity in social sciences. The ANOVA results of this regression indicate that the model is statistically significant with an F-value of 7.234 (P<.001). Neither gender nor the number of collaborators is significant in this model.

Table 10. OLS regression analysis – Social science

	Unstandardized Coefficients	Std. Error	Standardized Coefficients	t	Sig.
	B		Beta		
(Constant)	.777	1.132		.686	.500
Gender	1.233	1.297	.171	.950	.352
No mobility	3.264	1.266	.465	2.579	.017

a. ANOVA : F=7.234 (P<0.001)

b. Dependent Variable: annual average publication of career total (normal count--all publications) since doctoral degree obtained

CHAPTER 6

CONCLUSION AND POLICY IMPLICATIONS

6.1 Summary of main findings

In order to figure out impacts of discipline mobility on scientific productivity, I first examined scientists' bachelors and highest degrees by disciplines and regressed the annual average publication of career total (normal count to all publications) since doctoral degree obtained on gender, the number of collaborators, and 4 dummy variables: no change, a discipline change in level 1, level 2, and level 3. From the results of this study, I found several meaningful points as follows;

1. More than half (59.2%) of total scientists have different bachelors degrees from their highest degrees. Natural sciences have the lowest degree of mobility (19%) across disciplines and life sciences have the highest degree of mobility (77%) across the disciplines.

2. Natural sciences have the highest percentage (94%) of scientists who have the same bachelors degree field as their highest degree field. Social sciences have the lowest percentage (69%). None of the natural scientists have life, social, or humanities field as their bachelors degree field.

3. The relationship between discipline mobility and productivity

-. Natural sciences: Higher degree of mobility across the disciplines is negatively associated with their productivity.

-. Applied sciences: Scientific productivity is positively associated with the number of collaborators or other factors regardless of scientists' discipline mobility in applied sciences.

-. Life sciences: Higher degree of mobility across the disciplines is positively associated with scientific productivity.

-. Social sciences: Scientists who the same bachelor degree field as their highest degree field are likely to have higher productivity.

6.2 Policy Implications

As many previous studies pointed out, scientists acquire and deploy their technical skills and resources by "formal education." While I was not able to examine all the elements and relationships of the educational background of scientists and their productivity, this study has profound implications for the S&T educational policy.

First of all, this study has direct implications for recent educational policy to facilitate multidisciplinary education in universities. The recent changes of research patterns to application-oriented research leads to an increase of multidisciplinary education in universities. For instance, the National Academy of Sciences suggests that undergraduate and graduate students should take multiple skills developed by experience in multiple disciplines (2005). This now raises the question, "is this multidisciplinary experience positively associated with their productivity throughout all disciplines?" This study shows that natural sciences have highest percentage of scientists who have the same bachelors degree field as their highest degree field and higher degree of mobility across the disciplines is negatively associated with their productivity. On the contrary, for life sciences, higher degree of mobility across the disciplines is positively associated with scientific productivity. From a policy standpoint, the differences are particularly important. The results imply that the effects of scientists' discipline migration on scientific productivity vary from discipline to discipline, and the significant factors related to scientific productivity are also different from discipline to discipline. Therefore, in order for institutions or organizations to make decisions and to analyze S&T policy needs, they need more consideration of discipline specific characteristics.

REFERENCES

Allison, Paul D. and J. Scott Long (1990) Departmental Effects on Scientific Productivity, *American Sociological Review*, 55: 469-478.

Anderson, S (1996) The Wage and Employment Impact of Immigrant Scientists and Engineers in High Technology. *International Educator*, NAFSA: Association of International Educators.

Arora, Ashish and Alfonso Gambardella (1996) The Impact of NSF Support for Basic Research In Economics. IDEAS working paper.

Atkinson, R.C. (1990) Supply and Demand for Scientists and Engineers: A National Crisis in the Making (in Association Affairs) *Science*, 248: 425-432.

Babu, A. Ramesh and Y.P. Singh (1998) Determinants of Research Productivity, *Scientometrics*, 43 (3): 309-29.

Baum, Archie J. (1977) The specialist: His philosophy, his disease, his cure. Delhi: Macmillan Company of India. 27

Bayer, Alan E. and John C. Smart (1991) Career Publication Patterns and Collaborative "Styles" in American Academic Science. *Journal of Higher Education*, 62(6): 613-636.

Beaver, D and Rosen, R (1979) Studies in Scientific Collaboration: Part II-Scientific Co-authorship, Research Productivity and Visibility in the French Scientific Elite, 1799-1830, *Scientometrics*, 1 (1): 133-149.

Becher, Tony (1989) Academic tribes and territories: Intellectual inquiry and the cultures of disciplines. Milton Keynes, Eng.: Society for Research into Higher Education and Open Univ. Press.

Becker, G. (1962) 'Investment in human capital: A theoretical analysis,' *Journal of Political Economics* 70 (5): 9- 49.

Becker, G. (1964) Human capital. New York: Columbia University Press

Becker, Gary (1993) *Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education.* 3rd Ed, Chicago, University of Chicago Press.

Bellas, Marcia L. and Robert K. Toutkoushian (1999) Faculty Time Allocations and Research Productivity: Gender, Race, and Family Effects, *The Review of Higher Education*, 22 (4): 367-90.

Bourdieu, P. (1986), 'The forms of social capital,' In Richardson, J. G. ed., *Handbook of theory and research for the sociology of education* New York, Greenwood.

Bourdieu, P. and Wacquant, L. (1992), '*An invitation to reflexive sociology*,' Chicago, University of Chicago Press.

Bourke, P and Linda B. (1998) Institutions and the map of science: matching university departments and fields of research. *Research Policy*, 26: 711-718

Bozeman, Barry and Craig Boardman (2003) *Managing the New Multidiscipline, Multipurpose University Research Centers.* Washington, DC, IBM Endowment for the Business of Government.

Bozeman, Barry, James Dietz, and Monica Gaughan (2001) Scientific and Technical Human Capital: an Alternative Model for Research Evaluation. *International Journal of Technology Management*, 22 (8): 616–630.

Bozeman, Barry and Elizabeth Corely (2004) Scientists' Collaboration Strategies: Implications for Scientific and Technical Human Capital. *Research Policy*, 33(4): 599-616.

Carliner, Geoffrey (1980) Wages, Earnings, and Hours of First, Second, Third Generation American Males. *Economic Inquiry*, 18(1): 87-102.

Cole, Stephen and Jonathan R. Cole (1967) Scientific output and recognition: a study in the operation of the reward system in science, *American Sociological Review*, 32 (3): 377-90.

Coleman, J.C. (1988), 'Social capital in the creation human capital,' *American Journal of Sociology* 94: 95-120.

Coleman, J.C. (1990), '*Foundations of social theory*,' Cambridge, The Belknap Press of Harvard University Press.

Collins, Randall (1986) Is 1980s sociology in the doldrums? *American Journal of Sociology*, 91:1336-1355

Crane, Diana (1965) Scientists at Major and Minor Universities: A Study of Productivity and Recognition, *American Sociological Review*, 30 (5): 699-714.

Crane, Diana (1972) Invisible colleges. University of Chicago Press, Chicago

De solla Price, D and Beaver D (1966) Collaboration in an visible college. *American Psychologist*, 21: 1011-1018

Dietz, James S (2004) *Scientists and Engineers in Academic Research Centers – An Examination of Career Patterns and Productivity*. Doctoral Dissertation, Georgia Institute of Technology, February 2004.

Fox, Mary Frank (1992) Research, Teaching, and Publication Productivity: Mutuality Versus Competition in Academia. *Sociology of Education,* 65(4): 293-305.

Freeman, R.B., 1986. Demand for education. In: Ashenfelter, O., Layard, R. (Eds.), Handbook of Labor Economics. Amsterdam, North Holland.

Freeman, R.B., 1989. Labor Markets in action: Essays in Empirical Economy. Harvester Wheatsheaf, London.

Gaughan, Monica and Barry Bozeman (2002) Using curriculum vitae to compare some impacts of NSF research grants with research Center funding. *Research Evaluation,* 11 (1): 17-26.

Godin, Benoit (2003) The impact of research grants on the productivity and quality of scientific research. *INRS.* 2003.

Goodlad, Sinclair (1979) What is an Academic discipline? In Cooperation and Choice in Higher education, ed. Roy Cox (London: University of London) ERIC ED 181 836

Gordon, Michael (1980) A Critical Reassessment of Inferred Relations between Multiple Authorship, Scientific Collaboration, the Production of Papers and Their Acceptance for Publication. *Scientometrics,* 2:193-201.

Hagstrom, Warren O. (1964) Anomy in scientific communities. *Social Problems* 12:186-195

Hargens, L. (1975) *Patterns of Scientific Research: A Comparative Analysis of Research in Three Scientific Fields.* The ASA Rose Series in Sociology.

Hargens, Lowell L. and Lisa Kelly-Wilson (1994) Determinants of disciplinary discontent. *Social Forces,* 72(4):1177-1195

Heckhausen, Heinz. (1972) Discipline and Interdisciplinarity. *Interdisciplinarity: Problems of Teaching and Research in Universities.* Paris, OECD, 83-89

Katz, Sylvan J and Martin, Ben R (1997) What is Research Collaboration? *Research Policy.* 26 (1): 1-18.

Klein, J.T. (1996). Crossing boundaries. Knowledge, disciplinarities and interdisciplinarities. Charlottesville, VA: University Press of Virginia.

Kyvik, Svein and Teigen, Mari (1996) Child Care, Research Collaboration, and Gender Differences in Scientific Productivity. *Science, Technology, & Human Values,* 21 (1): 54-71.

Lawrence, Janet H. and Robert T. Blackburn (1988) Age as a Predictor of Faculty productivity: Three Conceptual Approaches, *Journal of Higher Education*, 59(1): 22-38.

Levin, S. G. and Stephan, P.E. (1991) Research Productivity over the Life Cycle: Evidence for Academic Scientists. *American Economic Review,* 81: 114-132.

Long, J. Scott (1978) Productivity and Academic Positions in the Scientific Career, *American Sociological Review*, 43 (6): 889-908.

Long, J. Scott and Mary F. Fox (1995) Scientific Careers: Universalism and Particularism. *Annual Review of Sociology*, 21: 45-71

Long, J. Scott and R. McGinnis (1981) Organizational Context and Scientific Productivity. *American Sociological Review,* 46: 422-442.

Mahlck, Paula (2001) Mapping gender differences in scientific careers in social and bibliometric space, *Science Technology & Human Values*, 26 (2): 167-90.

Mangematin, V. (2000) PhD job market: professional trajectories and incentives during the PhD. *Research Policy*, 29:741-756

Meltzer, Bernard N. (1949) The Productivity of Social Scientists, *American Journal of Sociology*, 55 (1): 25-9.

Miller, Raymond (1982) Varieties of interdisciplinary approaches in the social sciences. *Issues in Integrative Studies* 1:1-37

National Academy of Sciences (2005) *Facilitating Interdisciplinary Research.* Committee on Facilitating Interdisciplinary Research, National Academy of Sciences, Washington, D.C. National Academy Press.

National Research Council (1987) *The New Engineering Research Centers: Purposes, Goals, and Expectations.* Cross-Disciplinary Engineering Research Committee, National Research Council, Washington DC: National Academy Press.

National Research Council (1998) *Trends in the early careers of life scientists.* Washington DC: National Academy Press.

OECD (2002), Frascati Manual – Proposed Standard Practice for Surveys on Research and Experimental Development. Paris, France: OECD

Pantin, C.F.A. (1968) The relations between the sciences. Cambridge: Cambridge Unv. Press

Pao, Miranda Lee (1982) Collaboration in computational musicology. *Journal of the American Society for Information Science,* 33(1): 38-43.

Parker, Linda (1997) *The Engineering Research Centers (ERC) Program: An Assessment of Benefits and Outcomes.* Engineering Education and Centers Division, National Science Foundation, Arlington, Virginia.

Polanyi, M. (1967) The Tacit Dimension. London, Cox & Wyman

Polanyi, M. (1969) The logic of tacit inference: Knowing and being. London, Routledge & Kegan Paul

Pravdic, N and Oluic-Vukovic, V (1986) Dual approach to multiple authorship in the study of collaborator / scientific output relationship. *Scientometrics,* 10: 259-280.

Price, D. J. and Beaver D (1966) Collaboration in an invisible college. *American Psychologist,* 21: 1011-1018.

Qin, J., F.W. Lancaster and B. Allen (1997) Types and Levels of Collaboration in Interdisciplinary Research in the Sciences, *Journal Of The American Society For Information Science,* 48 (10): 893-916.

Reskin, B (1977) Scientific productivity and the reward structure of science. *American Sociological Review.* 42 (3): 491-504.

Rich, Daniel and Robert Warren (1980) The intellectual future of urban affairs: Theoretical, normative, and organizational options. *Social Science Research* 17, 2:53-66

Rinia, Ed J., Thed N. Van Leeuwen, Eppo E. W. Bruins, Hendrik G. Van Vuren and Anthony F. J. Van Raan (2002) Measuring knowledge transfer between fields of science. *Scientometrics*. 54(3):347-362

Rogers, Juan D. and Barry Bozeman, (2001) "Knowledge Value Alliances": An Alternative to the R&D Project Focus in Evaluation. Science, *Technology and Human Values,* 26(1)

Rose, Richard (1976) Disciplined Research and undisciplined problems. *International Social Science Journal*, 28 (1): 106-107

Schultz, Theodore W. (1963), '*The economic value of education,*' New York, Columbia University Press.

Stankiewicz, Rikard (1979) The Size and Age of Swedish Academic Research Groups and Their Scientific Performance. In *Scientific Productivity: The effectiveness of research groups in six countries.* Frank K. Andrews (ed). Cambridge University Press. Unesco.

Stephan, Paula E and Sharon G. Levin (1992) *Striking the Mother Lode in Science: The Importance of Age, Place, and Time.* Oxford University Press.

Thompson, J.D., R.W. Hawkes, and R.W. Avery, (1969) Truth strategies and university organization, Educational Administration Quarterly, 5,5

Thompson, Mark E. and David A. Brewster (1978) Faculty behavior in low paradigm versus high paradigm disciplines: A case study. *Research in Higher Education*, 8, 169-175

Toulmin, Stephen (1972) The variety of rational enterprises in human understanding. Princeton: Princeton Univ. Press 364-411

Tien, Flora F. and Robert T. Blackburn (1996) Faculty Rank System, Research Motivation, and Faculty Research Productivity, *Journal of Higher Education,* 67 (1): 2-22.

Whitley, R.D. (1978) The organization of scientific work in 'Configurational' and 'Restricted' sciences, *International Journal of sociology,* 8, 1-2, 95-112

Xie, Yu and Kimerlee A. Shauman (1998) Sex Differences in Research Productivity: New Evidence about an Old Puzzle. *American Sociological Review,* 63: 847-870.

Zuckerman, Harriet (1967) Nobel Laureates in Science: Patterns of Productivity, Collaboration, and Authorship. *American Sociological Review*, 32 (3): 391-403.

Zuckerman, Harriet (1972) Age, Aging, and Age Structure in Science. In *The Sociology of Science: Theoretical and Empirical Investigations.* Robert K. Merton. The University of Chicago Press.